04/02/07

Incident Involving 30-Ah Li-ion Cell at NASA Glenn Research Center:

Abstract
The key lesson learned from the February 17, 2006 cell explosion incident is that PC-based test-systems, even those having built-in watchdog monitors, can lose control and malfunction. In the case of lithium-ion cell/battery testing, the stored energy can be released explosively causing considerable injury and damage to facilities. The investigation showed that although the Arbin system has a built-in watchdog monitor, the circumstances of the incident defeated the action of the watchdog and allowed the cycler to continue operation without control. An upgrade to the most recent version of Arbin software (version 4) was provided as a fix to the presumed control problem. This upgrade included newer EPROM's for the cycler microprocessor. Investigation revealed that similar incidents have occurred at other NASA centers with a variety of PC-based test instruments. JPL suffered an incident with Maccor testers and the GRC fuel cell group observed similar problems with LabView software. This is not exclusively an Arbin problem, but an issue with all PC-based systems.

In this incident, it was fortunate that the event occurred after-hours with no-one in the room. The facility arrangement placed control consoles adjacent to the test chamber doors. Had someone been in the room during the event, they would have been exposed to hot debris and toxic combustion products. It was also fortunate that the exploded cell stayed inside the chamber after the door was forced open. If the cell had been ejected into the room it could have caused serious facility damage by impact and possibly caused a fire in the facility.

Measures taken
1. Improved safety monitors: In addition to the software/firmware upgrade provided by Arbin Instruments, an independent watchdog monitor has been implemented for use with "large" cells (>3 Ah). An independent voltage limiting circuit has also been developed and is being used for in-house testing of the Mars Lander battery, in addition to the independent watchdog.

2. Facility rearrangement: Since the incident, chambers have been arranged to open towards the back of the room. Test consoles and Arbin hardware have been located out of the path of the chamber doors.

3. Communication: Immediately after the GRC incident was understood, e-mail alerts were shared with points-of-contact at JSC and JPL. Li-ion cell manufacturers Eagle-Picher and Lithion were also informed that an apparent cycler failure had led to a cell explosion. In addition, a summary of the GRC incident was shared with other U.S. Government battery personnel at the 74th Lithium Battery Technical /Safety Group Meeting, Dayton, Ohio, September 6-7, 2006.

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Incident Involving 30-Ah Li-ion Cell at NASA Glenn Research Center

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Incident Summary

- 30-Ah Li-ion aerospace cell vented explosively during room-temperature, LEO testing.
- Occurred off-hours (4:50 AM), no injuries.
- Physical damage to test chamber, test-computer.
- Hot debris ejected from chamber scorched surfaces within ~10 feet of the chamber. No fire in facility.

Facility

Pressure build-up forced open door of 30 cu. ft. chamber.

Door knocked PC onto floor.

Cell ricocheted off chamber walls but remained inside chamber.

Exploded Cell

Rupture disc vented.

End-plates in place but bent.

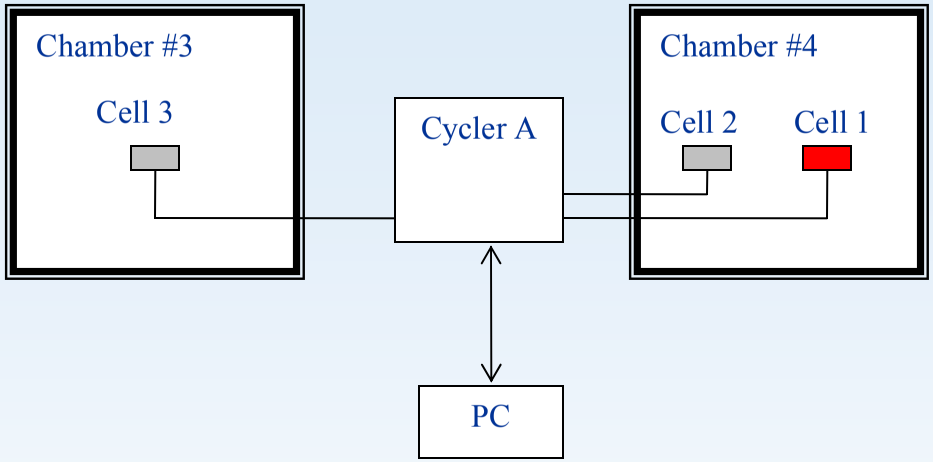
Case seam-weld ruptured.

Incident Timeline

Events		Delay, days
Incident – testing of Li-ion cells halted at GRC	2/17/2006	
Cleanup of Complete/Access to Data	3/1/2006	12
Cause of Incident Understood	3/6/2006	17
Corrective Measures Identified	4/18/2006	60
Corrective Measures In-place	6/14/2006	117
Safety Committee Review/Approval	6/27/2006	130
Testing Resumed	7/19/2006	152

Testing shut down for 5-months

Structure of Test Incident



- 3 cells under test.
- 2 separate chambers.
- One PC/cycler controlling all three tests.
- Cell 1 vented explosively.
- Cell 2 was not damaged.

Timing of Incident

Files recovered from PC showed normal test operation up to 2:30 AM.

After 2:30 AM, the PC stopped logging data for all three tests.

One of the cells vented explosively at 4:50 AM.

What was happening during the missing 140-minutes?

Reconstruction of Data

1. Measure OCV of undamaged cells after incident.
2. Compare voltage after incident with last recorded data point.

Results show that the cycler maintained flow of current to cells, without PC control.

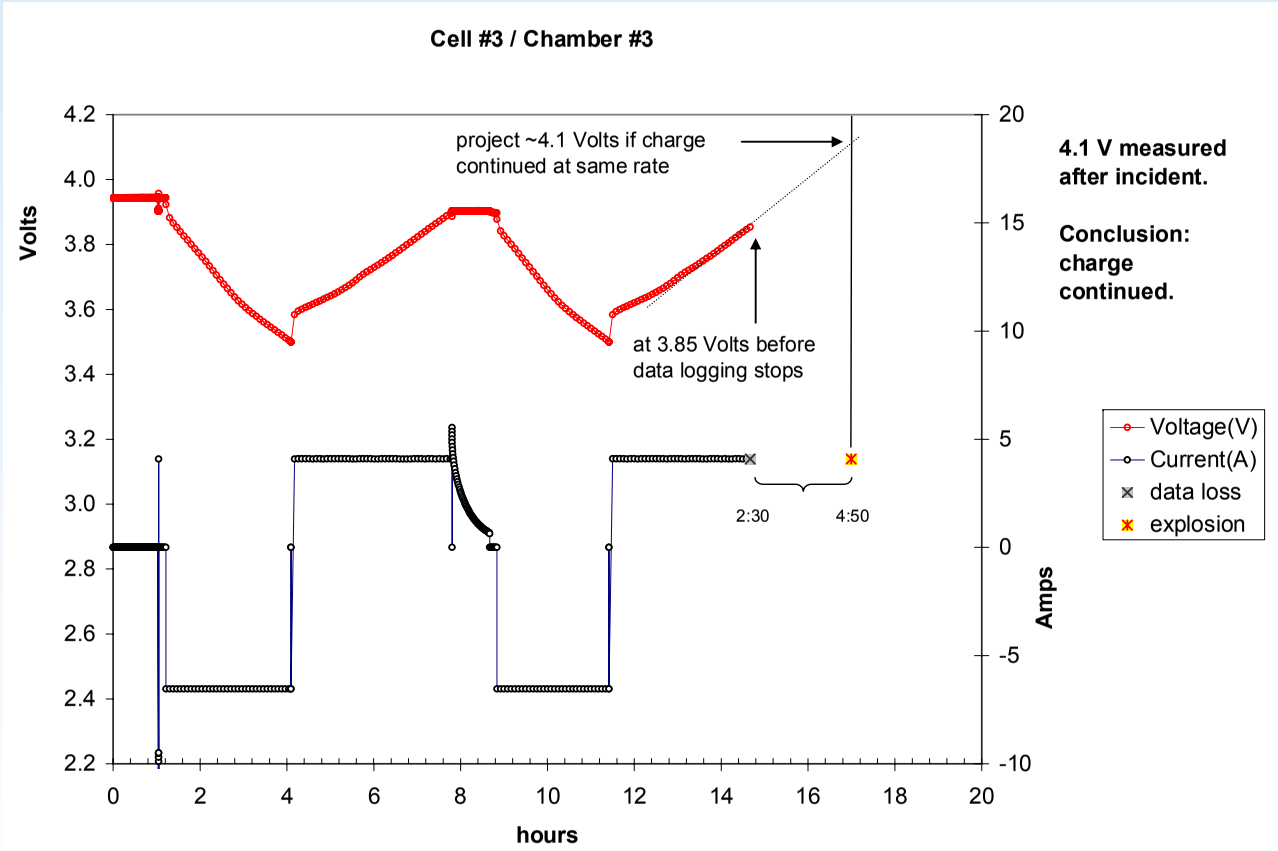
Reconstruction of Data Cell #3

Cell is at 3.85 V and charging at 4 A at last logged data-point.

If charge continued, cell would be at 4.1 V at the time of the incident.

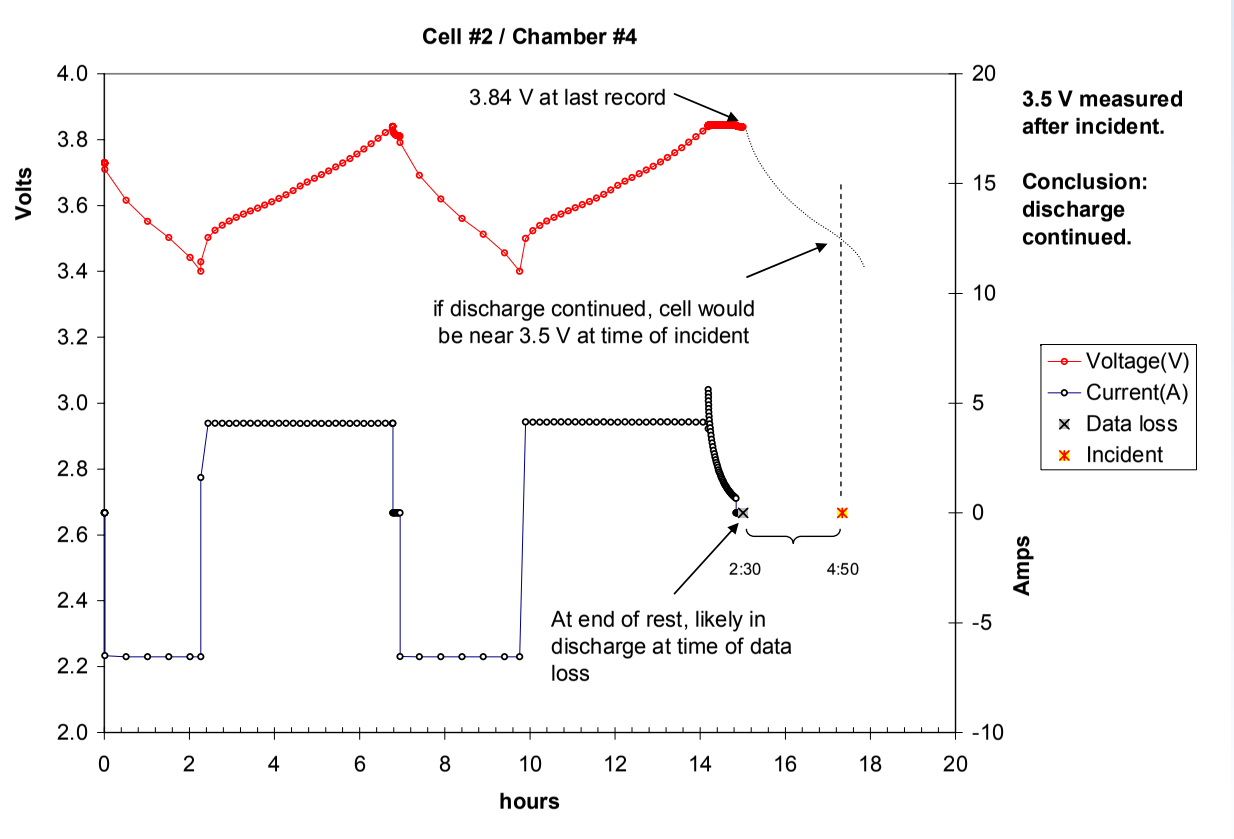
Matches OCV of 4.1 V measured after incident.

The 3.9 V upper cutoff was ignored.



Reconstruction of Data Cell #2

- Cell is at 3.84 V, at end of rest at last logged data-point.
- Likely to be in discharge at 6.5 A.
- If discharge continued, cell would be at 3.5 V at the time of incident.
- Matches OCV of 3.5 V measured after incident.

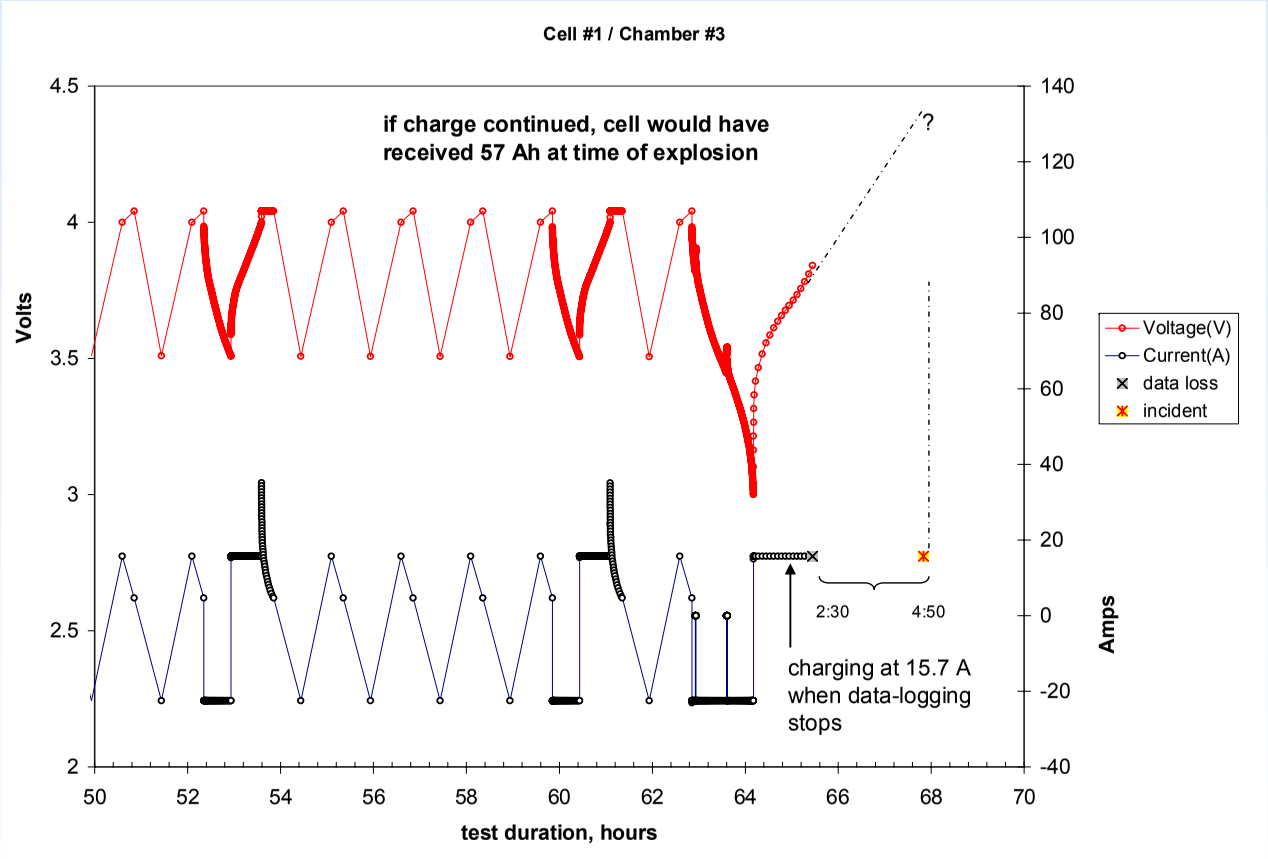


Reconstruction of Data for Exploded Cell

If charge continued at same rate as last data point, cell would have absorbed 57 Ah at the time of the incident.

Nearly two-times the nominal capacity!

Severe overcharge of exploded cell.



Corroborating Data

1. Johnson Space Center: Observed identical lock-up incident during attended testing.

2. Cycler vendor concurred that a Windows operating system fault could cause system to lock-up (in older versions of software).

Partial solution: upgrade control software

Investigation also revealed test incidents at other NASA Centers and commercial organizations, with different brands of PC-based, cycler hardware.

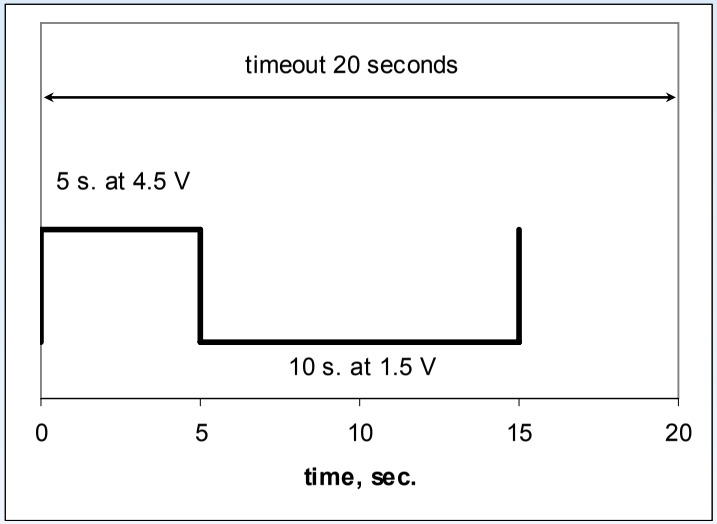
Corrective Actions

1. Installation of most up-to-date software on PC and firmware on all cyclers.
2. Installation of independent “watchdog” (for cells larger than 3 Amp-hours). Independent voltage monitor added for “large” cells.
3. Rearrangement of facility and chambers to protect personnel and property in the event of an overpressure incident.
4. Upgraded procedures for additional inspections and verification of test-schedules.

Independent Watchdog

Approach

- One channel of cycler is dedicated to continuously run regular pulse profile.
- Commercial timer monitors dedicated channel voltage.
- If pulse not detected within time-out interval, timer relay opens.
- Disconnects power to entire cycler.



Features:

- Loss of cycler control is detected within 20-seconds.
- Requires user intervention to restart system.
- Power loss to timer circuit or PC also shuts down cycler.

Conclusions/Comments

Incident was caused by PC control failure and fault in the built-in cycler watchdog system.

Fault could not be reproduced in testing. It is suspected that a Windows message-box caused the lock-up.

A removable flash-drive (left in the USB port of the PC) is suspected as possible cause of the Windows fault – this is the author's conjecture.

Any PC-controlled test system could suffer a similar failure: auxiliary safety monitors are essential.

Acknowledgements

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